THE NICKEL BULLETIN

A MONTHLY SUMMARY OF CURRENT INFORMATION

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VOLUME 28 NUMBER 9

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

The Charpy Impact Test: Properties of Low-Alloy Nickel-Chromium-Molybdenum Steel

D. E. DRISCOLL: 'Reproducibility of Charpy Impact Test.' *Amer. Soc. Testing Materials, Preprint* 93d, June, 1955; 5 pp.

This paper reports results of an extensive series of tests made to establish the validity and reproducibility of the Charpy impact test.

A special heat of steel (of the S.A.E. 4340 nickel-chromium-molybdenum type), in which a high degree of homogeneity had been ensured, was used to provide 18,000 blanks. The material was divided into three lots of approximately 6,000 specimens and was heat-treated to three energy levels. Two hundred specimens at each energy level were tested in Charpy machines manufactured by two different companies, and deviation and average energy values were recorded. The tests were made in the Watertown Arsenal Laboratory.

The results lead to the conclusion that 'in general the wide scatter sometimes encountered in tests with the Charpy machine is due to poor quality of steel, poor heat-treatment, or both, and the variations in machines are due to poor testing techniques, the poor condition of the Charpy machine, or possibly both.' The test results recorded in this paper appear to justify the view that, when properly conducted, the Charpy test is accurate and reproducible.

The remainder of the standard specimens prepared from the special heat of steel are being used to check Charpy impact machines elsewhere in the U.S.A., to determine the causes of variations encountered.

NICKEL

Nickel-Copper Ores in the Sudbury Region, Ontario

C. MAMEN: 'Nickel Rim Mines, Ltd. A Property Description.' *Canad. Mining Jnl.*, 1955, vol. 76, June, pp. 56–61.

A general description is given of the area worked by Nickel Rim Mines, Ltd., which is located on the eastern rim of the Sudbury basin. Some 760 tons of ore are mined per day. The geology of the ores is described, the history of development is outlined, and a detailed account is given of mining methods used on this property, with particular reference to diamond-drill blast-hole stoping.

Diffusion of Other Elements in Nickel and Nickel-Titanium Alloy

R. A. SWALIN: 'Solid-State Diffusion of Several Elements in Nickel at Elevated Temperatures.' *Dissertation Abstracts*, 1954, vol. 14, pp. 2032–3.

A detailed account is given of the technique employed, and data are presented relating to diffusion rates of manganese, aluminium, titanium and tungsten in nickel at 1100°–1300°C. The diffusion coefficient of manganese in a nickel-titanium alloy was also investigated. A summary of the findings is given in *Jnl. Applied Chemistry*, 1955, vol. 5, Apr., p. i–545.

Sintered Nickel Accumulator Plates

A. B. MUNDEL: 'A Sintered Plate Nickel–Cadmium Battery.' *Direct Current*, 1954, vol. 2, No. 2, pp. 53–6.

The article describes Sonotone alkaline accumulators, which employ sintered nickel positive plates, with cadmium negative plates, and in which the electrolyte is aqueous potassium hydroxide. The accumulators have the advantage of small size and low internal resistance, and are able to deliver large peak currents and a major proportion of their total capacity in a short period. The batteries are mechanically strong, and operate satisfactorily over a wide temperature range.

Nickel-Alkaline Battery for Use in Aircraft

'Lightweight Alkaline Battery for Aircraft.' *Engineer*, 1955, vol. 200, July 22, p. 125.

A lightweight, 24V alkaline battery for emergency duties in high-speed aircraft has been developed by Nife Batteries, Ltd., Redditch, in conjunction with the Ministry of Supply, to provide power for turn and slip indicators and for cockpit lighting. The weight is less than 3 lb., and the overall dimensions are 4·25 in. × 4·25 in. × 3·375 in. The new battery, which is available also for civil aircraft, is designed to operate without leakage of the electrolyte under aerobatic conditions at reduced barometric pressures equivalent to altitudes of up to 60,000 ft. It is built to withstand stresses of 30 *g*. in any direction. The cells are assembled in shock-resistant polystyrene containers, and increased mechanical strength is achieved by a special method of construction which is illustrated in this note.

Photometric Determination of Nickel in Copper-base Alloys

F. J. VERSAGI: 'Photometric Nickel Determination.' *Foundry*, 1955, vol. 83, July, pp. 158, 160, 162, 165.

Errors of appreciable magnitude encountered in the course of routine application of the photometric dimethylglyoxime method for determination

of nickel in copper-base alloys led to a detailed study of the technique. Using the method recommended by the American Society for Testing Materials (see *Methods for Chemical Analysis of Metals*, 1950, p. 292), the effects of the following variables were studied: concentration of reagent, temperature, foreign ions, time, and nickel concentration. Details are given, in the present paper, of the respective series of tests, from which the following conclusions were reached:—

'The amount of dimethylglyoxime must be carefully controlled. For production control, the limit should be 3 ml$\pm$0·5 ml. For precise work the dimethylglyoxime should be dispensed with a burette.

'Temperature variations in a normal laboratory, even on a given day, must be compensated for, and the absorbance index should be checked by running a standard along with the samples if the temperature has changed more than 5°F. Over a period of time it may be possible to establish absorbance indices for various temperatures.

'In spite of the theoretical consideration that greatest photometric accuracy is obtained at 36·8 per cent. T (approximately 0·43 A), the cumulative effect of all error-producing variables in this method is too great at the nickel concentration required (0·4–0·5 mg./100 ml.). Errors are minimized and greater accuracy is obtained if the nickel concentration is so controlled as to cause the readings to fall between 50 and 70 per cent. T (approximately 0·15–0·30 A).

'Bromine water must be kept at full strength, especially when work is with higher concentrations of nickel. This precaution will prevent the formation of a colloidal precipitate not readily visible.

'Citric acid and ammonium hydroxide additions are not critical within the limits of normal procedural error.

'Accuracy is reduced when a single calibration curve is set up using different alloys. Since the nickel-dimethylglyoxime colour reaction is known to follow Beer's law, it is necessary only to plot one curve, using a single alloy, to ascertain the linearity of the instrument. Thereafter it is sufficient to determine the absorbance index of any other alloy by running a known nickel concentration some distance from the origin.

'For very precise work, the best method appears to be that of running a standard with the unknown samples and using the absorbance index found for that series alone. Such a procedure cancels out errors of wave-length settings, variable slit widths, and other procedural errors which may have varied from the time of initial calibration.'

Resistance of Nickel to Oxygenated Water

See abstract on p. 154.

Oxidation Characteristics of Nickel

See abstract on p. 145.

Self Diffusion of Nickel

H. BURGESS and R. SMOLUCHOWSKI: 'Note on Self-Diffusion of Nickel.' *Jnl. Applied Physics*, 1955, vol. 26, Apr., pp. 491-2.

The authors comment on the absence of published information on self-diffusion in nickel, and report results of measurements over the range 250°–1250°C.

'The technique used was that of plating the isotope Ni^{63} on the surface of a piece of nickel and diffusing it at various temperatures. The measurements were made by measuring the drop of activity of the surface. The particular feature of Ni^{63} is that its activity is a very soft beta radiation, which can be measured only by special techniques. In this work a Tracerlab gas flow counter was used with good success. The softness of the beta radiation of nickel has the great advantage that the measured activity corresponds quite closely to the activity of the surface alone: the contribution of the deeper layers plays a small rôle and thus the well-known difficulty of accounting for it exactly is minimized. The absorption coefficient for the beta activity was estimated from data obtained with thin Formvar layers, as $\mu 1000\ cm^{-1}$. The diffusion coefficients were measured in the temperature range from 250° to 1250°C. At 1000°C. the diffusion coefficient is $1{\cdot}5 \times 10^{-12}\ cm^2 sec^{-1}$ and the activation energy lies in the range 61,000 to 65,000 cal/mole.'

ELECTRODEPOSITION AND OTHER COATING METHODS

Electroless Nickel Plating: Advantages, Limitations, Applications

J. L. CHINN: 'A New Look at Electroless Nickel Plating.' *Materials and Methods*, 1955, vol. 41, May, pp. 104–6.

This is a highly condensed and semi-popular assessment. The following points are made:—

Advantages

(1) Cost savings can be effected by using the electroless process, due to its ability to plate ordinarily inaccessible areas, the possibility of forming hard strong surfaces on relatively soft, light-weight materials, or the provision, to close tolerances, of corrosion- or wear-resistant surfaces on relatively inexpensive materials.

(2) Uniformity of thickness is a further advantage; plating occurs wherever the material is in contact with the solution, and thickness of coating is dependent only on temperature and time of immersion.

(3) Susceptibility to hydrogen embrittlement is lessened.

Limitations

The chief disadvantage, *vis-à-vis* electroplating, is the higher unit cost of the electroless process, but this constitutes no argument in the case of complex parts which could not be satisfactorily plated by electrodeposition.

Design Considerations

Base Metals. All types of steel, copper, and copper alloys can be plated, also some types of aluminium alloy, and brazed and silver-soldered surfaces. One type of titanium alloy has been coated by this process.

Theoretically, there is no limit to the thickness of the plating which can be produced by the electroless process, but for most purposes cost considerations impose economic limitations. Thicknesses recommended are as follows:—

For indoor protection 0·0005 in.
For mild outdoor protection 0·001 in.
For severe outdoor service 0·0015–0·002 in.
For abrasion-resistance 0·001–0·003 in.

Properties

Adhesion. Standard tests have shown that, due to a combination of mechanical and chemical bonding, the adhesion of electroless coatings is superior to that of conventional electrodeposited coatings.

Corrosion-Resistance. As rated by the standard A.S.T.M. salt-spray test, corrosion-resistance is good; an example quoted is that of a steel specimen carrying a coating of 0·0021 in. electroless nickel, which withstood attack for 288 hours without rusting.

Hardness. Minimum hardness of the coatings, as plated, is Rockwell C 43; a hardness of C 55 or above can be obtained by a post-plating heat-treatment.

Wear-Resistance. Due to the varying wear conditions encountered in service, no generalization is possible, but it can be stated that the coatings have inherent lubricating characteristics, and that in specific cases they have been found to be superior in wear-resistance to other finishes.

Cost

As in conventional electroplating processes, cost rises as the thickness of the electroless plate increases, as surface area increases, or as tolerances become closer, and unit cost is relatively higher for small quantities. Two additional factors have to be considered:—(1) it is usually cheaper to plate an entire part than to mask and plate selectively; (2) plating of inner surfaces of tubes or cylindrical parts raises problems in removal of interior surface contamination, such as welding scale or brazing flux.

Applications

Electroless nickel coatings have been successfully used for coating—

complex parts which could not be plated by conventional electrolytic methods, due to inadequate throwing power of the electrolytes;

miniature parts, such as instrument components, fine gears, and threads, where dimensional accuracy, uniform thickness of plating, and relatively close tolerances are essential;

internal areas and pipes, cylinders, etc., which could not be coated by electrodeposition: for example, electroless nickel deposits have been successfully applied to the interiors of solenoids and to components of hermetically sealed units;

relatively inexpensive bases, making possible economy in expenditure on 'special', e.g., corrosion-resistant, materials. In some cases weight reduction may also be achieved, as by using nickel-coated aluminium alloys instead of heavier materials;

electronic components, such as wave guides, contacts and printed circuits. In addition to providing solderability and corrosion-resistance, this type of finish increases surface conductivity and, in printed circuits, maintains continuous contact without edge build-up;

electrical parts in which humidity would cause damage. Miniature electric motors have operated satisfactorily after prolonged humidity tests which have corroded and 'frozen' unplated rotors.

Further uses of electroless nickel include—

masking, in selective nitriding, using a nickel coating of 0·006 in.;

protection, during storage, of steel parts. A deposit of 0·0004-in. thickness has been estimated as adequate for protection of some steel parts for periods up to about six years;

building-up over-machined holes, threads, splines, serrations and other irregularly shaped parts;

miscellaneous unusual requirements, e.g., coating of wire, to bring it to a diameter not produced in routine manufacture.

NON-FERROUS ALLOYS

Diffusion of Other Elements in Nickel and Nickel-Titanium Alloy

See abstract on p. 143.

Indium Alloys: Review of Literature

S. VALENTINER: 'The Alloys of Indium.'
Zeitsch. f. Metallkunde, 1955, vol. 46, June, pp. 442–9.

An annotated survey of the literature on binary and a few ternary alloy systems containing indium; supported by a *bibliography* of 86 items. Work on the indium-nickel system is included in the review.

Elevated-Temperature Properties of Nickel-Tungsten Alloys

See abstract on p. 153.

Oxidation Characteristics of Cobalt-Nickel Alloys

S. F. FREDERICK and I. CORNET: 'The Effect of Cobalt on the High-Temperature Oxidation of Nickel.' *Jnl. Electrochemical Soc.*, 1955, vol. 102, June, pp. 285–91.

The investigations described in this paper covered high-purity nickel and cobalt and alloys at intervals throughout the series. The specimens, in sheet form, were oxidized in air at temperatures ranging from 800° to 1405°C. Duration varied from a minimum of 13 minutes for pure cobalt at 1405°C. to a maximum of 1,638 minutes for pure nickel at 806°C.: for a given material the time range was also wide. Results were satisfactorily consistent.

They show that additions of up to 11 per cent. cobalt have only a slight effect on the oxidation rate of nickel. Higher percentages, however, caused rapid increase in rate of oxidation, especially when the cobalt content was above 60 per cent. The authors' findings indicate that the absolute value of the oxidation rate of pure nickel is lower than the relevant values previously reported in the literature.

The activation energy for oxidation of pure nickel in the range 800°–1400°C. was found to be 51,000 cal./mole, as compared with the figure of 45,000 cal./mole reported by other investigators. The activation energy for the oxidation of pure cobalt was observed to vary: a value of 28,800 cal./mole was found for the temperature range 900°–1300°C. In the binary alloys the activation energy for oxidation in the range 900°–1400°C. decreased with rise in cobalt content.

The results obtained are discussed in relation to the principal literature of the subject, to which comprehensive reference is given in the *bibliography*.

Influence of Nickel on High-Temperature Properties of Cast Copper Alloys

J. O. EDWARDS: 'Short-Time Elevated-Temperature Properties of Three Copper-base Casting Alloys.' *Amer. Foundrymen's Soc., Preprint* 55-3, May, 1955; 3 pp.

As a result of the steady rise, during the past few years, of steam temperatures and pressures in boiler practice, increasing interest has centred on the elevated-temperature properties of copper-base casting alloys. Research on copper-nickel-tin alloys (with and without small amounts of lead) has shown that such materials develop useful properties in the age-hardened condition, and the most promising of the alloys studied are now being subjected to long- and short-time tests at various temperatures within the range which is of interest in steam plant.

In the age-hardening experiments it was found that an alloy of the Ni-Vee type (copper 88, nickel 5, tin 5, zinc 2, per cent.) showed maximum increase in strength after heat-treatment, and that an alloy containing copper 80, nickel 5, tin 5, zinc 5, lead 5, per cent. also responded favourably. The U.S. standard Navy M bronze, on the other hand (containing copper 85·5, tin 6, zinc 4, lead 1·5, per cent., but no nickel) showed little or no response to ageing.

In the tests now reported these three alloys were subjected (after optimum ageing treatment) to short-time tensile tests at the following temperatures: room, 550°, 600° and 650°F. (288°, 316° and 343°C.). The results indicate that the addition of nickel confers improved strength at elevated temperatures, a conclusion which is subject to confirmation by creep tests. It is suggested that alloys of these types may be suitable for valve seats, discs, glands, bushings and similar valve or pump trim applications. In such parts, operating in 550°F. (288°C.) steam, boiler water, or similar environments, improved performance should be realized from the increased strength and hardness of the alloys containing nickel.

Atmospheric Corrosion-Resistance of Copper-base Alloys

See abstract on p. 155.

Resistance of Nickel-containing Materials to Oxygenated Water

See abstract on p. 154.

Photometric Determination of Nickel in Copper-base Alloys

See abstract on p. 143.

CONSTRUCTIONAL STEELS

Transition Temperature Welded Nickel Steel Plate

T. N. ARMSTRONG and W. L. WARNER: 'Effect of Welding on Transition Temperature of Nickel Steel Plate.' *Welding Jnl.*, 1955, vol. 34, May, pp. 209S-15S.

Low-carbon 2½ per cent. nickel steel plate has been generally used for low-temperature service for more than twenty years, e.g., in equipment employed in de-waxing lubricating oils, in which temperatures down to about −50°F. (−45°C.) are involved. The criterion of suitability of the steel has been its ability to meet a minimum Charpy keyhole notch-bar impact specification of 15 ft.-lb. Production practice, especially deoxidation procedures, has been improved to ensure consistent properties and grain size in the steel. As temperatures of chemical processing have been progressively lowered it has become necessary to increase the nickel content of the steel plate, in order to meet the specification impact requirements, and a 3½ per cent. nickel steel has gradually come into use. This material is used for equipment working at temperatures as low as −150°F. (−100°C.) and has also largely displaced the lower-nickel grade for the −40° to −100°F. (−40° to −75°C.) region. The record of the 3½ per cent. nickel steel is entirely satisfactory in pressure vessels operating at temperatures down to −150°F. (−100°C.), and its inclusion in A.S.T.M. Specification A 300 and in the A.S.M.E. Unfired Pressure Vessel Code demonstrates general acceptance of the material.

Numerous research investigations have added to knowledge of the influence of composition and methods of processing on transition temperature, with the result that it is now possible for the designer to select, with confidence, a steel that will be serviceable within specified sub-zero ranges. More recently attention has been directed towards a study of the effects of design and of fabricating operations, on the transition temperatures of complete structures, since it is increasingly recognized that a specific transition temperature in a component such as a plate does

not guarantee the same transition temperature in a structure made from it.

Welding is one of the major factors which require consideration in this connexion, and the research reported in this paper was specifically directed towards determination of the effect of welding on the low-temperature impact properties of 1-in. thick plate of $3\frac{1}{2}$ per cent. nickel steel conforming to Grade D of A.S.T.M. Specification A 203-53T and to Class 3 of A.S.T.M. Specification A 300-53T. The composition of the steels is shown in the table below:—

C	Si	Mn	S	P	Ni	Yield		U.T.S.		Elongn.
%	%	%	%	%	%	p.s.i.	t.s.i.	p.s.i.	t.s.i.	%
0·15	0·15	0·57	0·018	0·013	3·39	56,600	25·3	76,800	34·3	29
0·12	0·16	0·56	0·033	0·018	3·48	53,400	23·8	73,200	32·7	27

Charpy impact tests, keyhole notch, were made at room temperature, and at successively lower temperatures, until decided embrittlement was encountered. Impact values were then plotted against temperature. In addition, the fractured surfaces of the broken impact specimens were examined, and the percentage of shear or fibrous area (ductile) was recorded, in comparison with the cleavage area (brittle). Percentage of ductile fracture was then plotted against test temperature. The effect of variation in heat-treatment, on impact properties, was included in the investigation, and although the plate used throughout the present tests was of uniform thickness, the influence of thickness of plate is discussed, on the basis of the work of other investigators.

The welded specimens were prepared by joining two pieces of the nickel steel plate, each $1 \times 5 \times 15$ in., with a butt weld, along the 15-in. dimension, using $\frac{3}{16}$-in. electrodes conforming to A.W.S. classification E 8015. Details are given of the tensile properties of typical weld metal. Impact determinations were made, at normal and sub-zero temperatures, on specimens representing four welded conditions:—

Plate normalized, welded; specimens tested as welded

Plate normalized, welded; stress-relieved

Plate water-quenched and tempered, welded; specimens tested as welded

Plate water-quenched and tempered, welded; stress-relieved.

A complete temperature-energy transition curve was plotted from results obtained from test specimens having the bottom of the notch located at the interface of the weld metal and the heat-affected zone, for the normalized and welded plate, and a fracture-temperature transition curve was drawn for the same specimens. Curves were also plotted from results of tests in which the bottom of the notch was in the centre of the heat-affected zone, in the outer edge of the heat-affected zone, and in the unaffected area. In addition, slow-bend tests were made on specimens in each of these four conditions. The transition temperature in this case was selected as the temperature at which a lateral contraction of 1 per cent. was obtained across the width of the specimen at the fracture.

The results, reported *in extenso*, show that tempering or stress-relieving treatment slightly improves the Charpy impact (keyhole-notch) properties of normalized $3\frac{1}{2}$ per cent. nickel steel plate at the three temperatures used (70°, −100° and −150°F.: 21°, −75° and −100°C.). Pronouncedly higher impact properties were obtained, at all three test temperatures, in quenched-and-tempered plate. The fracture appearance of broken Charpy specimens bears a direct relation to the Charpy impact values, and may be used as a criterion of transition temperature.

Charpy impact properties of this steel appear to be not appreciably affected by increase in plate thickness from $\frac{1}{2}$ to 1 in., but values for 2-in. thick plate are slightly lower.

The impact properties at various locations in the welded area were not always so high as those in the unwelded plate. The lowest values usually occurred at the outer edge of the heat-affected zone, and at the interface of the weld metal and the heat-affected zone. At temperatures down to −150°F. (−100°C.) the Charpy value was in no case below 15 ft.-lb., nor was the ductile fracture less than 20 per cent.

In the slow notch-bend tests the transition temperature was slightly below −100°F. (−75°C.) for the as-welded normalized plate, but for the other three conditions the transition temperature was −150°F. (−100°C.) or below.

The authors conclude that 'welding does not appreciably lower the transition temperature of low-carbon 3½ per cent. nickel steel plate, particularly if the welds are stress-relieved.'

Understressing of Steel to Raise the Fatigue Limit

H. E. FRANKEL and J. A. BENNETT: 'Understressing as a Means of Eliminating the Damaging Effect of Fatigue Stressing.' *Amer. Soc. Testing Materials, Preprint* 71, June 1955; 9 pp.

It is well known that the fatigue strength of metals can be considerably improved by mechanical treatments such as shot-peening and surface-rolling, which work-harden the surface and produce in it compressive stresses. It has been shown also that understressing, i. e., application of a large number of cycles of stress below the fatigue limit, also raises the fatigue limit and the fatigue life of ferrous metals, but there has previously been relatively little investigation of the effect of such treatment on specimens which have already been damaged by stressing above the fatigue limit. Research on possible methods of eliminating fatigue damage is now in progress at the U.S. National Bureau of Standards, and this report presents the results of the first phase of the investigation.

The work was carried out on a quenched-and-tempered steel of the S.A.E. 4340 type, of the following composition: carbon 0·44, silicon 0·29, manganese 0·66, sulphur 0·025, phosphorus 0·014, nickel 1·74, chromium 0·77, molybdenum 0·23, per cent. The tensile strength of the steel in the heat-treated condition was 156,900 p.s.i. (70 tons per sq. in.), yield strength (0·2 per cent. offset) 147,000 p.s.i. (64·7 tons per sq. in.), reduction of area 60 per cent., and hardness 32–34 Rockwell C.

Rotating-beam tests showed that the damaging effect of fatigue stressing 10 per cent. above the fatigue limit could be eliminated by understressing and by 'coaxing' (application of a large number of cycles at each of a series of stresses of increasing amplitude). The improvement was greater for tests in which the initial stress was close to the fatigue limit than for those in which the coaxing was started at a lower stress. Damage produced by a stress 30 per cent. above the fatigue limit was not completely eliminated by understressing treatments.

Nickel-Alloy Steel Pinions in Blooming Mill

'Nickel Steel Pinions Set Service Record.' *Iron Age*, 1955, vol. 175, June 16, p. 110.

The following record has been supplied by the United States Steel Corporation, with reference to operations in its works at Youngstown, Ohio:

'Over 3½ million tons of steel, produced during 37 months of uninterrupted operation, is the record established by three cast nickel-alloy steel pinions on the 43-in. blooming mill. Previous life for pinions in the mill was 5½ months, with an average production of 477,612 tons. The cast alloy-steel pinions thus produced about seven times as much steel, and operated about seven times as long without interruption.

'Recently the mill was shut down and the pinions were removed while the housings and bearings were repaired. Examination showed that the pinions were still not worn out.

'A combination of a tough, wear-resistant alloy steel with a specially developed and improved heat-treatment has contributed substantially to the performance of the pinions, which are distinguished by a particularly high degree of shock resistance.'

The Charpy Impact Test: Properties of Low-Alloy Nickel-Chromium-Molybdenum Steel

See abstract on p. 143.

Corrosion-Resistance of Nickel-containing and other Low-Alloy Steels

See abstract on p. 153.

Determination of Nickel in Steel in Low- and High-Alloy Steels

BRIT. IRON AND STEEL RESEARCH ASSOCN.: METHODS OF ANALYSIS COMMITTEE 'Determination of Nickel. Development of a Method Applicable to all Classes of Steel.' *Jnl. Iron and Steel Inst.*, 1955, vol. 180, July, pp. 262–9.

Two British Standard methods for determination of nickel in steel have been published:—

B.S. 1121: Part 2 is for analysis of permanent-magnet alloys and steels containing nickel in the range 7–35 per cent., together with 10–30 per cent. of cobalt and other elements, e.g., copper;

B.S. 1121: Part 6 covers estimation of residual amounts of nickel (less than 0·5 per cent.) in carbon and low-alloy steels.

Although giving entirely satisfactory results within the specific fields mentioned, both methods are of strictly limited application, and co-operative research has been carried out with a view to devising a procedure which would be applicable to a wider range of nickel-containing ferrous-base materials. Particular attention was devoted to a study of the known interfering effects of copper and cobalt.

An abridged account of the investigation is given in this report, and, as a result of the work, recommendations have been made to the British Standards Institution for two procedures, applicable, respectively, to steels of varying cobalt content.

In Method No. 1, which is for general application to all classes of steel and iron, subject to the qualification that the amount of cobalt present in the test solution should not exceed 0·15 g., the principle is as follows:—

The sample is dissolved in hydrochloric acid and oxidized with nitric acid, and the nickel is precipitated as its glyoxime complex from ammoniacal citrate solution. The filtered complex is dissolved in mineral

acid and nickel is determined by titration with potassium cyanide and silver nitrate.

In Method No. 2, which is for determination of nickel in high-cobalt steels, nickel and cobalt are converted to complex cyanides, the cobalt cyanide is oxidized with hydrogen peroxide, to the stable cobalti-form, and nickel is precipitated with dimethylglyoxime, using formaldehyde to decompose the nickelocyanide selectively. The filtered glyoxime is dissolved in mineral acid and nickel is determined with potassium cyanide and silver nitrate.

Full details of procedure for both methods are included in the report and results of typical control determinations are recorded.

Alloy Steels in the Petroleum Industry

See abstract on p. 154.

HEAT- AND CORROSION-RESISTING MATERIALS

Effect of Heat-Treatment and Structure on High-Temperature Properties of Nickel-Chromium-(Cobalt)-base Alloys

W. BETTERIDGE and R. A. SMITH: 'The Effect of Heat-Treatment and Structure upon Creep Properties of Nimonic Alloys between 750° and 950°C.'
Amer. Soc. Testing Materials, Preprint 94d, June, 1955; 11 pp.

It has for some time been a well-established fact that increasing amounts of solute elements improve the creep-resistance of a solvent, and that additions of small amounts of a variety of solutes are frequently more effective than a corresponding amount of a single solute. Precipitation of a second phase from a saturated solid solution produces further marked increase in creep-resistance, and the effect, on creep properties, of the type and nature of the precipitate and of the amount of hardening which it causes has been the subject of extensive research. The authors of the present paper refer to major investigations on hardenable nickel-chromium-(cobalt)-base alloys, as exemplified by the Nimonic series, in which precipitation is secured by the inclusion of small amounts of titanium and aluminium. Attention is directed also to the kindred alloy, Inconel X, and to the complex carbide-hardened alloy N-155, containing iron, with chromium 20, nickel 20, cobalt 20, per cent., and small amounts of other alloy elements.

Since previous work had given no clear indication of the optimum amount and distribution of the precipitated phases, the tests described in the present paper were planned to study this aspect, as influencing the creep behaviour of alloys of the types shown in the table below.

The creep tests were of relatively short duration, with the primary object of providing data relevant to the conditions operative in aircraft gas-turbine blades. The temperature range covered was 750°-950°C., and in view of the known influence of solution-treatment temperature (as well as of precipitation) on creep behaviour, tests were made on alloys subjected to four different methods of heat-treatment.

The results, illustrated by numerous photomicrographs and curves, are discussed in relation to (1) influence of titanium and aluminium content, (2) effect of heat-treatments on creep properties of the nickel-chromium-cobalt (Nimonic 90) alloys, and (3) effect of precipitation on properties of the nickel-chromium (Nimonic 80A) alloy. The following general conclusions are drawn:—

'The results obtained appear to some extent contradictory, and no clear conclusions can be drawn concerning the effects of structure on stress-rupture properties.

'From the comparative tests on the three heats of

Compositions of the Alloys Investigated

C %	Co %	Cr %	Ti %	Al %	Ni %
0·032	18·2	19·5	2·48	1·59	Substantially the balance
0·058	19·1	19·4	2·56	1·54	
0·074	18·8	19·9	2·00	1·12	
0·049	—	19·0	2·33	1·21	

Nimonic 90, it appeared certain that the highest stress-rupture properties were obtained with the greatest content of precipitated phases. This effect was particularly noticeable at the higher temperatures, at which, with approach of complete solubility, the differences were most marked.

'The curve for the nickel-chromium alloy (Nimonic 80A), however, shows no inflection in the rupture stress-temperature relation on crossing the temperature at which the structure changes from that of a matrix containing a dispersed phase to that of a complete solid solution. This observation suggests that the presence of the precipitated phase has no important effect on the rupture stress. The authors consider that it may be possible to reconcile these differing conclusions by assuming that the increase in stress-rupture strength due to the formation of a precipitated phase is, in these particular alloys, sufficient only to compensate for the decrease in strength due to the loss of the precipitated material from solid solution.

'The investigation of the effects of various heat-treatments, on the stress-rupture properties of Nimonic 90, showed that considerable differences could be produced and that these differences could not be explained wholly by change of grain size (resulting from change of solution temperature) or by changes in the conditions of precipitation of the hardening phase, $Ni_3(Ti,Al)$. Thus, a comparison of materials quenched from either 1000° or 1250°C. (1830° or 2280°F.) and aged for 16 hours at 700°C. (1290°F.) showed that increasing grain size resulted in marked embrittlement of the alloys, and lowered rupture strength at temperatures below about 850°C. (1560°F.). An intermediate treatment at 950°C. (1740°F.), following solution treatment at 1200°C. (2190°F.), completely restored the rupture strength by improving the ductility of the coarse-grained material. This effect has been correlated with grain-boundary precipitation of carbide.

'Finally, the improvement at higher temperatures in the relative strength of alloys quenched from 1250°C. (2280°F.) appears to indicate that important structural changes may occur immediately prior to, or in the early stages of, testing at such temperatures. It is known, for example, that the hardness of Nimonic 90 aged at 700°C. (1290°F.) for 16 hours can be changed to that characteristic of the same material aged at 850°C. (1560°F.), by treatment for about 1 hour at the higher temperature. The usefulness of the conventional ageing treatments is thus clearly lessened as the temperature of testing or operation of these alloys is raised above 870°C. (1600°F.).'

Tension and Torsion Tests on Nickel-Chromium-(Cobalt)-base Alloys

E. D. WARD and W. G. TALLIS: 'Tension and Torsion Tests on Nimonic Alloys at High Temperatures.' *Amer. Soc. Testing Materials, Preprint* 94e, June 1955; 11 pp.

Although in high-temperature components of many types the main interest centres on creep and stress-rupture properties, results of conventional short-time tension and torsion tests are also significant, e.g., in making preliminary comparisons of the relative merits of different alloys, in estimating the stress ranges in which creep tests should be made, and in preliminary consideration of materials for new applications. Further development of very-short-life expendable propulsive units for missiles is likely to create increasing demand for such information.

This paper presents reference data obtained in conventional tension and torsion tests, at 20°–1000°C. (70°–1830°F.) on the nickel-chromium-base alloys Nimonic 75 and Nimonic 80A and the nickel-chromium-cobalt-base alloys Nimonic 90 and Nimonic 95. The alloys of this group are widely used for rotor blades and other components in British gas turbines. Since the 75 alloy has had little application for rotor blading, only the tension properties have been determined for this material; for Nimonic 80A and 90, the rotor-blade alloys principally used in Britain, both tension and torsion data are presented: for Nimonic 95, the most recent commercially developed alloy of the series, only tensile properties are yet available. The compositions of the alloys mentioned are given in the table on p. 151.

In all cases the material was in bar form, and had been processed, by forging and hot rolling, from normal production ingots of a single cast. Bar diameter varied between $\frac{5}{8}$ and $\frac{3}{16}$ inch. The Nimonic 75 was in the annealed condition, in which the alloy is generally used; the other alloys had undergone the standard heat-treatments specified for the respective types as giving optimum creep-resistance.

In most cases the tests were made at 20°C. (70°F.) and 100°C. (212°F.), and thence at 100°C. intervals up to 1000°C. (1830°F.).

The results are presented in a series of reference graphs containing the following data, *as a function of temperature:*—

For Nimonic 75, 80A, 90 *and* 95
- Tensile Limit of Proportionality
- Tensile 0·2 per cent. Proof Stress
- Ultimate Tensile Strength
- Elongation at Fracture
- Reduction of Area
- Tensile Elastic Modulus

For Nimonic 80A *and* 90
- Torsional Limit of Proportionality
- Torsional 0·2 per cent. Proof Stress
- Modulus of Rupture
- Twist at Fracture
- Modulus of Rigidity

The observations made lead to the following general conclusions:—

'The general trends of the properties with increase in temperature are similar for the various alloys, but the levels vary from one alloy to another. Nimonic 75 is the weakest of the series and Nimonic 90

Nimonic Alloys Tested

	C %	Co %	Cr %	Ti %	Al %	Ni %
Nimonic 75	0·13	—	19·33	0·35	0·12	bal.
Nimonic 80A	0·04	1·15	19·5	2·40	1·25	bal.
Nimonic 90	0·06	15·2	19·8	2·25	1·24	bal.
Nimonic 95	0·09	16·5	19·9	2·84	1·70	bal.

and Nimonic 95 are the strongest, there being little difference between the last two. The limit of proportionality and proof-stress values remain fairly constant, or fall only slightly, up to 600°C. (1110°F.) for Nimonic 75, and up to 700°C. (1290°F.) for the other alloys. For all the alloys, the ultimate tensile strength falls only slightly up to about 500°C. (930°F.), but above this temperature it decreases more rapidly. At 1000°C. (1830°F.), the strength properties of Nimonic 95 appear significantly higher than those of the other alloys, which are very similar. Ductility shows little change up to about 500°C. (930°F.): above that temperature there is a rapid drop to a minimum, which occurs at 600°–700°C. (1110°–1290°F.) for Nimonic 75, at 700°C. (1290°F.) for Nimonic 80A and Nimonic 90, and just below 800°C. (1470°F.) for Nimonic 95. After this minimum the ductility increases rapidly, reaching very high values at 900°C. (1650°F.) or above. Throughout the temperature range studied, Nimonic 75 has markedly higher reduction of area values than the other alloys, although up to 500°C. (930°F.) the elongation values for this alloy are similar to those of Nimonic 80A. The least ductile alloy at every temperature is Nimonic 95. The moduli of elasticity are fairly similar, but Nimonic 95 tends to show slightly higher values. Up to 600°C. (1110°F.), elastic modulus falls only slightly; above this temperature the fall is more rapid, but less so for Nimonic 90 and Nimonic 95 than for the other alloys.

'The torsion properties of Nimonic 80A and Nimonic 90 are similar in trend, the strength values for Nimonic 90 being a little higher up to about 800°C. (1470°F.) and then tending to be on the same level. In both cases the strength properties fall fairly slowly up to 700°C. (1290°F.), but above that temperature the fall is more rapid. Ductility of Nimonic 90, as measured by the angle of twist at fracture, is rather lower than for Nimonic 80A. It remains nearly constant up to 600°C. (1110°F.) for Nimonic 80A, and up to 650°C. (1200°F.) for Nimonic 90: there is then a fall over the range 700°–800°C. (1290°–1470°F.), followed by a rapid rise at higher temperatures. The modulus of rigidity values for the two alloys are very similar. There is a fairly slow fall up to 700°C. (1290°F.), but subsequently there is a more rapid decrease.'

Influence of Boron on Cast Cobalt-Nickel-Chromium-base Alloy

W. E. BLATZ, E. E. REYNOLDS and W. W. DYRKACZ: 'Influence of Boron on Cast Cobalt-base S-816 Alloy.' *Amer. Soc. Testing Materials, Preprint* 94a, June, 1955; 8 pp.

The authors describe an investigation of the effects of boron additions on the properties of S-816, an alloy of the following composition: carbon 0·40, silicon 0·40, manganese 1·2, chromium 20, nickel 20, molybdenum 4, tungsten 4, niobium+tantalum 4, iron 2, per cent., balance cobalt. The initial stages of the work covered both wrought and cast alloys containing boron up to 0·2 per cent.: later work was concerned with cast alloys only, in which boron contents up to 3 per cent. were used. The major criterion used for evaluation was the rupture properties in the range 1500°–1800°F. (815°–980°C.), and the principal object of the investigation was to find an alloy of a composition which, at temperatures above 1600°F. (870°C.), would give properties equivalent to those characteristic of wrought S-816 at 1500°F. (815°C.).

The conclusions reached are summarized below:—

Boron adversely affects forgeability of this type of alloy: with boron above 0·15 per cent. the material is unforgeable. At relatively low levels of boron cast alloys of the S-816 basis composition show higher rupture strengths at 1600° (870°C.) than are obtained in the modified wrought S-816 alloys. In cast alloys of this composition boron additions up to about 1 per cent. markedly improve rupture strength, but higher percentages of boron have the reverse effect. The boron-modified cast alloy of optimum composition shows, at 1650°F. (900°C.), rupture strength equivalent to that of wrought S-816 at 1500°F. (815°C.), and the boron-modified alloys have also good ductility at rupture. The boron-containing alloys have excellent casting properties,

which, combined with the fact that boron recoveries during melting are high, indicates that quality control on a production basis is feasible.

Compression-Creep Properties of High-Temperature Materials

L. A. YERKOVICH and G. J. GUARNIERI: 'Compression-Creep Properties of Several Metallic and Cermet Materials at High Temperatures.'
Amer. Soc. Testing Materials, Preprint 94f, June 1955; 23 pp.

Increasing demand for reduced weight/strength ratios in aircraft, coupled with other factors involved in high-temperature engineering, has created a creep-buckling problem in designing thin-walled structures, and in overcoming the difficulties so encountered, compression-creep data are urgently required. Development of cermet materials has added to the interest in this subject, since their inherently high compression strengths are an asset in some applications.

This paper gives an account of the design and operation of a compression-creep testing machine for determinations up to 1800°F. (982°C.), and records results of tests on wrought S-816 (cobalt-base alloy containing nickel, chromium and small amounts of other elements) and Nimonic 90 (nickel-chromium-cobalt-base alloy) at 1350° and 1600°F. (732° and 870°C.); on arc-cast and swaged molybdenum at 1600°F. (870°C.); on cast Haynes Stellite (cobalt-chromium-base alloy) at 1600°F. (870°C.), and on two cermets, K 162-B (nickel-bonded titanium carbide), at 1800°F. (982°C.) and Metamic LT-1 (chromium-base) at 1600°F. (870°C.).

A limited amount of comparison was made between the compression-creep and tensile-creep properties of the materials.

From the results the following tentative conclusions are drawn:—

'Comparison of tension-creep and compression-creep characteristics indicates that metals do not necessarily behave identically under static tension and compression stresses. The alloy S-816, in wrought bar form, shows an acceleration in creep at 1600°F. (870°C.) under compressive loading. Similar accelerated creep effects were observed for wrought bar Nimonic 90 in compression, as compared with published tension-creep data.

'Variations in tension compression creep behaviour for wrought alloys are probably related to microstructural and orientation effects generated in their processing.

'Comparisons of the tension- and compression-creep behaviours of cast Haynes Stellite 21 at 1600°F. (870°C.) show only small differences in creep behaviour associated with type of load.

'The creep-strength superiority, in compression, of the metal-ceramic composite K 162-B suggests that creep in tension is dependent upon metal-binder characteristics, and in compression upon the properties of the hard particles of the composite.'

Titanium-Carbide Materials Impregnated with High-Temperature Alloys

L. P. SKOLNICK and C. G. GOETZEL: 'Titanium-Carbide Products Produced by the Infiltration Technique.'
Amer. Soc. Testing Materials, Preprint 94g, June 1955; 7 pp.

In spite of much effort which has already been devoted to development of titanium-carbide-base cermets made by normal powder-metallurgy technique, it has not yet been found possible to secure, in such materials, the requisite toughness, either at ordinary temperatures or in the ranges which are of interest in high-temperature engineering, e.g., 1700°-2000°F. (925°-1095°C.). This paper reports work on a metal-bonded titanium-carbide material in which the metallic bonding material is not used in powder form, but is added in the liquid state by infiltration into the carbide matrix. A skeleton body of titanium carbide is prepared by pressing the powder at low pressures, sintering to form a coherent mass, and filling the voids of the skeleton with a high-strength, ductile, heat- and corrosion-resistant material.

The sintered body can be impregnated by several methods, depending on the type and density of the carbide skeleton being treated, and the composition of the infiltrant alloy.

It is shown that composites produced in this manner are characterized by much improved toughness.

The structures of titanium-carbide infiltrated with nickel-chromium-base alloy are illustrated, with notes on the importance of the size and form of the carbide particles, as influencing the impact-resisting quality of the infiltrated complex. A table in which the impact-resistance, at room temperature, 1600° and 1800°F. (870° and 982°C.) is compared with the properties of ordinary cermets and with those of X-40 cast alloy* demonstrates the improvement effected by infiltration, as compared with normal powder-metallurgy production, and indicates that there is promise of development of infiltrated materials having impact-resistance approximating that of metallic alloys. Some of the shapes and parts which can be produced by this method are illustrated and some potential applications of the process are suggested.

Electropolishing of Nimonic 80 Alloy

K. F. LORKING: 'Electropolishing Nimonic 80.'
Metal Finishing, 1955, vol. 53, May, pp. 64-6.

Two types of solution have been recommended for electropolishing of the nickel-chromium-base alloy Nimonic 80: (1) an aqueous phosphoric/sulphuric acid electrolyte, and (2) a bath containing glacial acetic acid and perchloric acid. This paper reports experiments made (in the Aeronautical Research Laboratories, Victoria, Australia) to determine optimum conditions for polishing in phosphoric/sulphuric acid baths.

* Cobalt-chromium-nickel base alloy containing tungsten.

Best results were obtained from a solution containing sulphuric acid 15, phosphoric acid 64, per cent., balance water, operated at a temperature of about 70°C., with a cell voltage of 2·5–2·8.

Nimonic Alloys in Marine Gas Turbine

'H.M.S. 'Grey Goose." *Engineer*, 1955, vol. 200, July 22, pp. 113–14.

Two experimental R.M.60 gas turbines of advanced design have been installed in the gunboat H.M.S. 'Grey Goose', in place of the original steam-turbine machinery, and the ship is now acting as a floating test bed. This article gives a description of the gas turbine, which has a total power of 10,800 b.h.p., as compared with the 8,000 s.h.p. of the steam machinery. Reference is made to materials of construction used in various parts of the new power plant, e.g., Nimonic 90 blading in the h.p. turbine, Nimonic 80 blading in the power turbine, and Nimonic 75 for the flame tubes.

Elevated-Temperature Properties of Nickel-Tungsten Alloys

I. I. KORNILOV and P. B. BUDBERG: 'Composition/Hot-Strength Diagram of Alloys of the System Nickel-Tungsten.' *Doklady Akad. Nauk S.S.S.R.*, 1955, vol. 100, Jan. 1, pp. 73–5.

The strength, at elevated temperatures, of binary alloys containing up to 50 per cent. of tungsten was determined. Maximum strength occurred at about 28 per cent. tungsten. The observations made are discussed in relation to the phases present in the respective alloys.

Corrosion-Resistance of Nickel-containing and other Low-Alloy Steels

J. C. HUDSON and J. F. STANNERS: 'The Corrosion-Resistance of Low-Alloy Steels.' *Jnl. Iron and Steel Inst.*, 1955, vol. 180, July, pp. 271–84.

This report is issued under the aegis of the Atmospheric Corrosion Sub-Committee of the Corrosion Committee of the British Iron and Steel Research Association.

It covers results obtained in a comprehensive long-term investigation of the behaviour of sixty low-alloy steels subjected, in the form of wire and strip, to corrosion tests in atmosphere and/or sea water, for periods up to 5 years. In addition, subsidiary tests were made on some rail steels and cast irons, and parallel laboratory atmospheric-corrosion tests were conducted. The experimental programme included the following tests:—

(*a*) outdoor exposure in atmosphere at Sheffield, for periods up to 5 years,

(*b*) total immersion in sea water, also for periods up to 5 years,

(*c*) intermittent spray test (sulphuric acid/sodium chloride solution) by the method described by Swinden and Stevenson,* details of which are given.

* Ibid, 1940, vol. 142, pp. 165-78.

The steels were of compositions selected to permit assessment of the effects of individual elements on corrosion-resistance: full analyses are recorded, and a critical review is made on the basis of composition.

The general conclusions are as follows:—

'Low-alloy additions are a valuable means of reducing the rusting of steel exposed to the atmosphere outdoors. Under these circumstances the most resistant low-alloy steels rust during the first year or two of exposure at only one-third the rate of unalloyed mild steel. With longer exposure, they appear to still greater advantage.

'The most useful alloying elements for this purpose are chromium, copper, and nickel. Aluminium and beryllium may also be of value. Otherwise, none of a wide variety of alloying elements tested was found to have had a marked effect on the resistance of steel to atmospheric corrosion.

'When immersed in sea water low-alloy steels show to less advantage, but under the more or less stagnant conditions described in the paper the addition of about 3 per cent. of chromium to mild steel roughly halved its wastage by corrosion over 5 years.

'The corrosion rates of plain carbon steels, over periods of several years in air or in sea water, are not markedly influenced by differences in their carbon contents. The results indicate that high-carbon steels are less corrodible in the atmosphere than low-carbon steels, but more so in the sea. The differences are not great, however, and are about 20 per cent. in both cases.

'Heat-treatment is not a major factor in determining the severity of corrosion of low-alloy steels over long periods of exposure to air and sea water, but it may have a pronounced influence in laboratory tests extending over a few weeks only. No evidence was obtained that sorbitizing affected the corrosion-resistance of rail steel exposed outdoors.

'There is little difference in the general corrosion of cast irons and plain carbon steels when immersed in sea water, although the former may be seriously weakened by local attack and graphitization. No general conclusion about the respective merits of the two types of material when exposed to the atmosphere can be drawn from this investigation.

'Laboratory tests of the intermittent-spray type yield only fair correlation with the results of outdoor exposure. This is probably because the rusting of the steels in the laboratory test does not proceed sufficiently far for the differences in the properties of the rusts on the various steels to become fully operative.'

Characteristics of Austenitic Steels as Influenced by Carbon Content

G. LILLJEKVIST and S. HANSEN: 'In which Cases should an 18–8 Steel with 0·03 per cent. Carbon or 0·05 per cent. Carbon or a Stabilized Steel be Chosen ?' *4th World Petroleum Congress, Rome*, June, 1955; *Section VII/B, Preprint* 7; 7 pp.

The paper is a contribution to discussion of the susceptibility of austenitic chromium-nickel steels

to intercrystalline corrosion, as influenced by carbon content. The opinions advanced are based on experience in the Avesta Steelworks, Sweden. Recommendations are made with regard to the specific types of service for which 18-8 chromium-nickel steels containing 0·12 max., 0·08 max., 0·05 max. or 0·03 max. per cent. of carbon are suitable, and also the range of applications in which 18-8 steels stabilized with titanium or with niobium may be used.

Resistance of Nickel-containing Materials to Oxygenated Water

C. J. LANCASTER: 'Corrosion Tests of Sixteen Materials in 500°F. Water at High and Low Velocities.'
U.S. Naval Engineering Experiment Station, Annapolis, Report E.E.S. 4A(21)966870: NS-200-020; 9 pp.+figures.

An extensive series of tests is under way at the Engineering Experiment Station, Annapolis, to determine the suitability of various metallic materials for constructional use involving contact with high-temperature water. Conditions of test are being varied from time to time to simulate those which arise in service. The present report covers experiments in which sixteen materials were exposed, at two velocities (10 ft./sec. and 1 ft./hr.) in water containing 20-30 ml./L. of oxygen at 500°F. (120°C.). All the specimens were in the form of flat tension specimens, not stressed during test. Those tested at high velocity were mounted in special slotted holders of austenitic chromium-nickel steel, which minimized contact corrosion: in low-velocity tests the specimens were mounted on austenitic chromium-nickel steel rods with $\frac{1}{16}$-in. washers of similar steel separating them.

The materials exposed are listed below:—

Straight 18-8 chromium-nickel steel (0·08 per cent. carbon max.) in the unwelded and welded conditions, and after sensitizing treatment.

The same steel surface treated by Malcomizing (a specialized type of nitriding).

Molybdenum-containing 18-8 chromium-nickel steel, in the unwelded and welded conditions, and after sensitizing treatment.

Inconel (nickel-chromium-iron alloy), unwelded and welded.

Monel (nickel-copper alloy containing 63-70 per cent. of nickel).

K Monel (aluminium-containing precipitation-hardening modification of Monel).

Commercially pure nickel.

Stainless iron (16-18 per cent. chromium).

Nickel-copper (70-30) alloy.

The high-velocity tests were continued for 90 days and the low-velocity series for 60 days.

As would be anticipated, the austenitic steels showed superior performance when tested at 10 ft./sec. in oxygenated water at 500°F. (120°C.). Of the materials in this group, the malcomized specimens showed the poorest resistance to attack, although it is considered that the high surface hardness resulting from such treatment may, in some cases, be advantageous. On the basis of weight loss, there was little difference between the straight 18-8 and the molybdenum-containing 18-8 chromium-nickel steels, and the test results show that the resistance of these steels to the conditions studied is not substantially altered by welding. Although the sensitized specimens also showed no serious deterioration, it is recommended that conditions involving such effects should be avoided wherever possible.

In the low-velocity tests on the austenitic materials no significant damage was observed as a result of deposits which might give rise to contact corrosion, but under the washers of similar material, used as spacers, these steels suffered contact corrosion. It is emphasized that in designs involving mechanical joints and other conditions producing crevices, consideration must be given to the susceptibility of such materials to this type of attack.

The pitting of Monel, nickel, and K Monel, observed in oxygenated water at both high and low velocities, indicates that caution should be exercized in using these materials in such conditions. Corrosion rate of the 70-30 copper-nickel alloy was high in both series of tests, but the corrosion loss was well distributed. The stainless iron showed fairly good behaviour, except for the occurrence of some rust spots, a condition promoted by the oxygen content of the water.

Alloy Steels in the Petroleum Industry

G. R. BOLSOVER and J. F. SEWELL: 'Alloy and Special Steels for the Petroleum Industry.'
4th World Petroleum Congress, Rome, June, 1955; *Section VII/B, Preprint* 1; 12 pp.

The paper comprises a brief review of recent developments in steels which are being used or are of potential value in equipment employed in the production and handling of oils of various types. Particular attention is given to stainless and heat-resisting steels: this section includes notes on factors affecting behaviour in service (e.g., surface finish, design, methods of polishing, etc.), the influence of inclusions, weld decay and methods for its avoidance, occurrence of sigma phase, and stress-corrosion. Information on sub-zero properties is also given, as being of particular interest in many branches of the oil industry.

In the second part of the paper the authors review some of the structural low-alloy steels which come into consideration in this field: mechanical test data are presented for typical chromium-molybdenum and chromium-molybdenum-vanadium steels, with special reference to the characteristics required in bolt material. Post-war developments in high-tensile low-alloy steels for engineering purposes are also considered, with emphasis on types suitable for welded construction.

Production of Holes of Small Diameter in Stainless Steel

H. G. JERRARD: 'Holes of Small Diameter in Stainless Steel.' *Jnl. Scientific Instruments*, 1955, vol. 32, June, p. 232.

A short, practical note, describing a method (developed in a research laboratory), for making circular holes of diameters less than 0·01 in. in stainless-steel discs of thicknesses varying up to 0·375 in. Close accuracy of contour was essential, and it was not possible to drill by normal methods.

Determination of Nickel in High-Alloy Steels

See abstract on p. 148.

Atmospheric Corrosion-Resistance of Copper-base Alloys

A. W. TRACY: 'Effect of Natural Atmospheres on Copper Alloys; 20-Year Test.'
Amer. Soc. Testing Materials, *Preprint* 91b, June, 1955; 10 pp.

The report analyses data obtained on eleven copper-base alloys exposed, for a 20-year period, in atmospheres of the following types: industrial; industrial marine; northern, tropical and extra-severe marine, and humid and dry rural. The tests were conducted under the aegis of the A.S.T.M. Committee B-3 on Corrosion of Non-Ferrous Metals and Alloys.

The materials tested comprised electrolytic tough-pitch copper; phosphorized copper; silicon, manganese and phosphor bronzes; high-tensile, red, and 70-30 brasses; Admiralty metal; copper-nickel-zinc alloy (75-20-5%), and copper-nickel-tin alloy (70-29-1%).

Charts record the behaviour of the respective materials, as determined on the basis of weight losses for 10- and 20-year periods and of changes in tensile strength. Comments are also made with regard to dezincification of some of the alloys. The specimens exposed were all in a stress-free condition and the tests were not designed to take account of liability to stress-corrosion cracking.

The paper includes a list of typical uses of the various grades of copper and copper alloys considered in the report.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Registered Trade Marks*.

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THAMES HOUSE · MILLBANK · LONDON S.W.1

PRINTED IN ENGLAND *by* WIGHTMAN MOUNTAIN LTD.
WESTMINSTER, LONDON, S.W.1